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Numerical and statistical aerodynamic performance analysis of NACA0009 and NACA4415 airfoils

NACA0009 ve NACA4415 kanat profillerinin sayısal ve istatistiksel aerodinamik performans analizi

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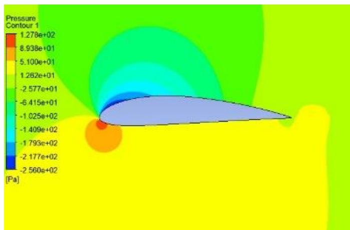
Numerical and Statistical Aerodynamic Performance Analysis of NACA0009 and NACA4415 Airfoils

Highlights

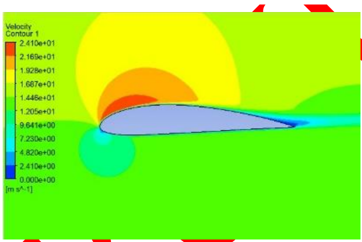
- *Angle of Attack*
- *Airfoil*
- *ANSYS Fluent*
- *Taguchi Method*
- *ANOVA*

Graphical Abstract

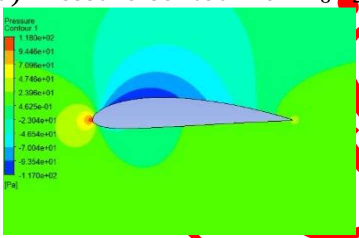
In the study, effects and optimum levels of angle of attack and airfoil type on performance such as lift coefficient, drag coefficient were evaluated using computational fluid dynamics code ANSYS FLUENT and Taguchi method with L16 orthogonal array including two control factors such as angle of attack and airfoil types such as NACA0009 and NACA4415.



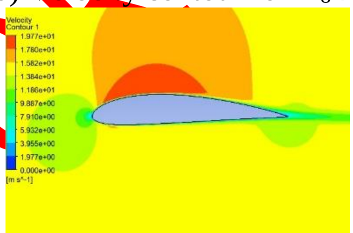
a) Pressure contour for A_8B_2



b) Velocity contour for A_8B_2



c) Pressure contour for A_1B_2



d) Velocity contour for A_1B_2

Figure. Pressure and velocity contours

Aim

The target of CFD study is to define the ideal levels of lift and drag coefficients due to various angles of attack of various airfoils. CFD analyzes were performed using the L16 orthogonal array in accordance with the Taguchi method

Design & Methodology

Lift and drag coefficient performances of NACA-0009 and NACA-4415 airfoils were evaluated using CFD and L16 orthogonal array based on Taguchi method

Originality

In literature, there are several researches including lift and drag performances of NACA airfoils, but there is no study with numerical and statistical lift and drag analyses at constant Reynold Numbers (Re).

Findings

CFD approach in ANSYS FLUENT is a software that is easy to implement and gives fast results compared to other methods.

Conclusion

The maximum lift and minimum drag coefficient were achieved by using NACA4415 airfoil compared to NACA0009 airfoil. The increase of the angle of attack leads to the increase on the lift and drag coefficients for both airfoils.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Numerical and Statistical Aerodynamic Performance Analysis of NACA0009 and NACA4415 Airfoils

Research Article

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ABSTRACT

In this numerical and statistical study, lift and drag coefficient performances of NACA-0009 and NACA-4415 airfoils were evaluated in accordance with various attack angle at constant velocity of wind. Lift and drag coefficients of airfoils was numerically determined by computational fluid dynamics code ANSYS FLUENT. Analysis design of numerical calculations was implemented using L16 orthogonal array based on Taguchi method. Angles of attack and airfoil types were considered as control factors. The optimum level and effect of each control factor on responses was statistically implemented using analyses of Signal-to-Noise ratio and variance. As a result of this study, maximum lift and minimum drag coefficient were achieved by using NACA4415 airfoil compared to NACA0009 airfoil. The increase of the angle of attack leads to the increase on the lift and drag coefficients for both airfoils.

Anahtar Kelimeler: Angle of attack, airfoil, CFD, Taguchi method, aerodynamic.

NACA0009 ve NACA4415 Kanat Profillerinin Sayısal ve İstatistiksel Aerodinamik Performans Analizi

ÖZ

Bu sayısal ve istatistiksel çalışmada, NACA-0009 ve NACA-4415 profillerinin kaldırma ve sürükleme katsayısı performansları, sabit rüzgar hızında çeşitli hücum açılarına göre değerlendirilmiştir. Kanat profillerinin kaldırma ve sürükleme katsayıları, hesaplamalı akışkanlar dinamiği kodu ANSYS FLUENT ile sayısal olarak belirlendi. Sayısal hesaplamaların analiz tasarımı, Taguchi yöntemine dayalı L16 ortogonal dizisi kullanılarak gerçekleştirilmiştir. Hücum açıları ve kanat tipleri kontrol faktörleri olarak kabul edildi. Her kontrol faktörünün tepkiler üzerindeki optimum seviyesi ve etkisi, Sinyal-Gürültü oranı ve varyans analizleri kullanılarak istatistiksel olarak uygulandı. Bu çalışma sonucunda NACA0009 kanat profiline kıyasla NACA4415 kanat profili kullanılarak maksimum kaldırma ve minimum sürükleme katsayısı elde edilmiştir. Hücum açısının artması, her iki kanat profili için kaldırma ve sürükleme katsayılarının artmasına neden olur.

Keywords: Hücum açısı, kanat profili, CFD, Taguchi yöntemi, aerodinamik.

1. INTRODUCTION

NACA Airfoil series are generally used in the aviation industry. These airfoils have various geometries. Having various geometries provides various lift and drag forces. In order to obtain high aerodynamic behavior of airfoils, it is generally desired to obtain high lift and low drag force. Various angles of attack are used to achieve this behavior. Angles of attack can directly affect the C_L and C_D of airfoils. An airfoil with the lowest drag and highest lift coefficients should be used during the flow [1-4]. In the literature, there are studies examining many airfoil behaviors [5-20]. In most of these studies, many angles of attack were discussed. In a research, C_L and C_D of NACA0012 airfoil made of 0.1524 m chord length were evaluated based on various angles of attack under 360000 Reynold Number and computational domain with rectangle geometry. In analyses, Navier-Stokes and panel techniques were used as computational method [21]. NACA0012 and NACA2412 airfoils were numerically investigated under various angles of attack utilizing ANSYS Fluent to achieve extreme lift to drag ratio. In analyses, Spalart-Allmaras, the k-epsilon RNG turbulence, the k-omega SST models were used [22]. In another study, lift and drag coefficients under various angles of attack in accordance with NACA0009 Airfoil were investigated under low Reynold Number using ANSYS Fluent. As a result of the analysis, the best aerodynamic performance for extreme lift to drag ratio was obtained under attack angle with 5 degrees [23]. In a study, NACA4415 C_L and C_D were calculated in accordance with various angles of attack and they found that the increase of the angle of attack up to 8 degrees increased the lift and drag coefficients. They also observed the effect of Reynold Numbers on the aerodynamic performance of airfoils [24]. C_L and C_D of

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the NACA4412 Airfoil were investigated depending on the various angles of attack and Reynold Numbers. In the study, it was determined that the increase in the Reynolds Numbers caused an increase in the lift and drag coefficients [4]. In another study, the analysis of aerodynamic analyses of airfoils including various geometries depending on various angles of attack was carried out. The k-omega SST turbulence approaches was utilized in the analyses. As a result of the study, the highest lift coefficient was obtained for NACA4415 at an angle of attack of 10 degrees [25]. In another study, lift and drag coefficients for NACA0015 Airfoil were investigated using experimental and numerical methods depending on various angles of attack. ANSYS Fluent software was utilized to carry out numerical analysis. The obtained numerical and experimental data were compared with each other and the differences were revealed [3]. In another study, CFD analyzes of NACA0012 and NACA4412 airfoils were implemented by ANSYS Fluent software using C-Mesh type at various angles of attack. In this research, the mesh size effect was examined and it was stated that 85000 mesh number could achieve the best results [26]. In a study, C_L and C_D at various angles of attack were solved in accordance with the NACA0012 airfoil and ANSYS Fluent software. The highest performance value of airfoil for C-Mesh type was calculated in the study [27]. In a study, the aerodynamic efficiency of airfoils with various geometries was investigated under many angles of attack. Calculations at the low speed were completed using the ANSYS CFD module. C_L and C_D were evaluated for each airfoil [28]. In literature mentioned, there are several researches including lift and drag performances of NACA airfoils, but there is no study with numerical and statistical lift and drag analyses at constant Reynold Numbers (Re). In this study, aerodynamic performance analysis of airfoils was carried out using ANSYS Fluent and Taguchi technique. In addition, the Taguchi method was used for the statistical analysis. Thus, optimum C_L and C_D were obtained using less analysis. With this aspect, this study will make a different contribution to the literature. Because, As evident from the literature review, there are various experimental and theoretical studies, but there is no study that uses the numerical and Taguchi method together.

2. NUMERICAL ANALYSIS

Numerical analysis of airfoils was carried out using computational fluid dynamics (CFD) program in finite element software ANSYS. In analyses, two airfoils were utilized such as NACA-0009 and NACA-4415. Coordinate of each airfoil was taken from NACA's airfoil database [29]. These coordinate data in ANSYS software were imported to generate the 2D geometries of the airfoils. NACA-0009 and NACA-4415 profiles were illustrated as 2D sketch in Figure 1a and 1b, respectively. C mesh for CFD analysis of each airfoil was employed.

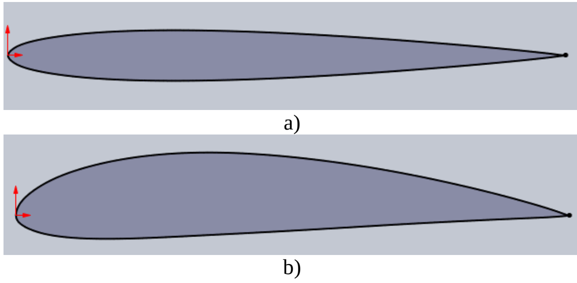


Figure 1. a) NACA-0009 Airfoil and b) NACA-4415 Airfoil

Chord length of airfoils were taken 1 m and was located at 12.5 chord length from the inlet. In mesh operations, 251000 nodes and 250000 elements were used. C-mesh including three-way velocity for each airfoil domain is intended and C-mesh type was presented in Figure 2.

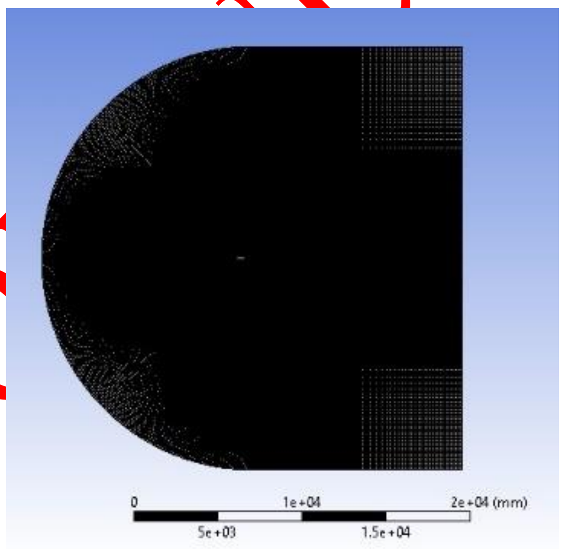


Figure 2. C-Mesh type

Absolute criteria values for continuity, x-velocity, y-velocity, and epsilon were taken as 10^6. In CFD analysis, many parameters were used as constant and these parameters were tabulated in Table1.

Table 1. Constant parameters

No	Parameters	Values
1	Fluid Type	Air
2	Inlet Velocity	14.6074 m/s
3	Chord Length	1 m
4	Density of Air	1.225 kg/m^3
5	Viscosity of Air	$1.7894*10^{-5}$ kg/m-s
6	Gauge Pressure	0
7	Turbulence Model	Realizable k-epsilon
8	Momentum	Second Order Upwind

In CFD calculations, realizable k-epsilon was used as turbulence model. This model was used in many studies [4, 21, 24, 26, 30]. The transport equations in accordance with k and ∈ based on the realizable k-∈ model are [31]:

$$\frac{\partial}{\partial t}(\rho k)+\frac{\partial}{\partial x_j}(\rho k u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right]+P_k+P_b-\rho\epsilon-Y_M+S_k \tag{1}$$

$$\frac{\partial}{\partial t}(\rho \epsilon)+\frac{\partial}{\partial x_j}(\rho \epsilon u_j)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial_\epsilon}{\partial x_j}\right]+\rho C_1 S_\epsilon-\rho C_2\frac{\epsilon^2}{k+\sqrt{\nu\epsilon}}+C_{1\epsilon}\frac{\epsilon}{k}C_{3\epsilon}P_b+S_\epsilon \tag{2}$$

$$c_1=max\left[0.43,\frac{\eta}{\eta+5}\right],\qquad \eta=S\frac{k}{\epsilon}\ ,\qquad S=\sqrt{2S_{ij}S_{ij}} \tag{3}$$

in which, P_k denotes the occurrence of incoming turbulent kinetic energy due to average velocity gradients. P_b is the emergence of turbulent kinetic energy under buoyancy. Y_M shows the contribution on the overall amount of dispersion for the fluctuating dilatation due to compressible turbulence. Also, C_2 and $C_{1\epsilon}$ are used as constant. σ_k and σ_ϵ refers to turbulent numbers known as Prandtl. S_k and S_ϵ indicate resource terms defined depending on the user.

$$\mu_t=\rho C_\mu\frac{k^2}{\epsilon} \tag{4}$$

$$C_\mu=\frac{1}{A_0+A_s\frac{kU^*}{\epsilon}} \tag{5}$$

$$U^*\equiv\sqrt{S_{ij}S_{ij}+\widetilde{\Omega_{ij}}\widetilde{\Omega_{ij}}} \tag{6}$$

$$\widetilde{\Omega_{ij}}=\Omega_{ij}-2\epsilon_{ijk}\omega_k\ ; \tag{7}$$

$$\Omega_{ij}=\ \bar{\Omega}_{ij}-\epsilon_{ijk}\omega_k \tag{8}$$

in which, $\widetilde{\Omega_{ij}}$ signifies the average rotation speed tensor observed around the rotating reference including the angular speed dependent on the ω_k value.

$$A_0=4.04,\qquad A_s=\sqrt{6}\cos\emptyset \tag{9}$$

$$\emptyset=\frac{1}{3}\cos^{-1}(\sqrt{6}W),\quad W=\frac{S_{ij}S_{jk}S_{ki}}{\tilde{S}^3},\quad \tilde{S}=\sqrt{S_{ij}S_{ij}},\quad S_{ij}=\frac{1}{2}\left(\frac{\partial u_j}{\partial x_i}+\frac{\partial u_i}{\partial x_j}\right) \tag{10}$$

$$C1_\epsilon=1.44, C_2=1.9, \sigma_k=1.0, \sigma_e=1.2 \tag{11}$$

where, C_μ is a function of the angular velocity of rotation in the system and turbulence fields (k and ∈) depending on the average tension and rotational speeds. ∅ represents the angle dependent on the cosine value. A_0 and A_s represent model constants. Lift coefficient, drag coefficient and Reynold Number were calculated using Equation 12-14 [26], respectively.

$$C_L=\frac{2F_L}{\rho V^2 c} \tag{12}$$

$$C_D=\frac{2F_D}{\rho V^2 c} \tag{13}$$

$$R_e=\frac{\rho V c}{\mu} \tag{14}$$

where, F_L and F_D are defined as lift and drag forces. C_L and C_D present lift and drag coefficients of airfoils. V expresses velocity of wind. ρ is used as density of air. Also, c and μ represent cord length of airfoil and dynamic viscosity of the fluid respectively.

3. STATISTICAL ANALYSIS

There are many statistical methods created using different levels of different parameters. One of these methods is the Taguchi method. The most important aim of this method is to obtain the optimum level by using few variables. With this aspect, it can save both time and cost. In this research, Taguchi method was implemented to calculate less optimum levels. CFD calculations were performed using the L16 orthogonal array in the Taguchi method. There are two control factors in this design. NACA Airfoil types were chosen as the second control factor. NACA-0009 and NACA-4415 are considered as airfoil types. While NACA-0009 Airfoil type was used as the first level of the second control factor, NACA-4415 Airfoil type was evaluated as the second level. Angle of attack was determined as the first control factor. Angles of attack were changed from 1 degree to 8 degrees. Each angle of attack represents each level of the first control factor. In total, 16 various CFD analyzes were implemented. The control factors used in the calculations and the levels for the control factors are given in Table 2.

Table 2. Variable Parameters

Factors	Icons	Levels							
Attack Angle	A	1°	2°	3°	4°	5°	6°	7°	8°
Airfoil Type	B	NACA-0009	NACA-4415	-	-	-	-	-	-

Lift and drag coefficients of airfoils were chosen as the outputs of the examination. As a result of the calculations, the "Larger is Better" methodology in accordance with the Taguchi method was selected to calculate the maximum lifting coefficient, while the "Smaller is Better" approach was considered for the minimum drag coefficient. The quality characteristics for “Larger is Better” and “Smaller is Better” are stated in Equation 15-16 [32], respectively.

$$(S/N)_{HB} for\ Cl=-10.log\left(n^{-1}\sum_{i=1}^{n}(y_i^2)^{-1}\right) \tag{15}$$

$$(S/N)_{SB} for\ Cd = -10.log\left(n^{-1}\sum_{i=1}^{n}(y_i^2)\right) \qquad (16)$$

4. RESULTS AND DISCUSSIONS

The target of CFD study is to define the ideal levels of lift and drag coefficients due to various angles of attack of various airfoils. CFD analyzes were performed using the L16 orthogonal array in accordance with the Taguchi method. Calculated CFD results and corresponding S/N ratio values are presented in the Table 3.

Table 3. Aerodynamic results for L16 orthogonal array

Runs	Design	Control Factors A	Control Factors B	Lift Coefficient C_L (-)	S/N ratio η (dB)	Drag Coefficient C_D (-)	S/N ratio η (dB)
1	A_1B_1	1°	NACA-0009	0.10634	-19.4661	0.01357	37.3503
2	A_1B_2	1°	NACA-4415	0.50045	-6.0128	0.00521	45.6654
3	A_2B_1	2°	NACA-0009	0.21160	-13.4897	0.01451	36.7696
4	A_2B_2	2°	NACA-4415	0.59439	-4.5186	0.00750	42.4952
5	A_3B_1	3°	NACA-0009	0.31422	-10.0553	0.01620	35.8081
6	A_3B_2	3°	NACA-4415	0.68681	-3.2633	0.01080	39.3307
7	A_4B_1	4°	NACA-0009	0.41134	-7.7160	0.01878	34.5266
8	A_4B_2	4°	NACA-4415	0.77793	-2.1812	0.01517	36.3832
9	A_5B_1	5°	NACA-0009	0.50281	-5.9719	0.02257	32.9301
10	A_5B_2	5°	NACA-4415	0.86600	-1.2496	0.02055	33.7429
11	A_6B_1	6°	NACA-0009	0.58788	-4.6142	0.02788	31.0935
12	A_6B_2	6°	NACA-4415	0.95096	-0.4368	0.02697	31.3811
13	A_7B_1	7°	NACA-0009	0.66437	-3.5518	0.03531	29.0418
14	A_7B_2	7°	NACA-4415	1.03280	0.2803	0.03452	29.2393
15	A_8B_1	8°	NACA-0009	0.72229	-2.8258	0.04612	26.7216
16	A_8B_2	8°	NACA-4415	1.10840	0.8939	0.04305	27.3197
Overall Means ($\bar{T}$)				0.62741	-	0.02242	-

According to Table 3, the overall means of the lift and drag coefficients were detected as 0.62741 and 0.02242, respectively. To choose the dominant levels of airfoils and angles of attack on lift and drag coefficients, Analysis of Variance (ANOVA) was operated. In addition, the influence ratios of each angle of attack and airfoil on the results were calculated using ANOVA. Analysis was conducted based on 95% confidence level. ANOVA outcomes of lift coefficient based on R-Sq = 99.96% and R-Sq(adj) = 99.92% and drag coefficient in accordance with R-Sq = 98.79% and R-Sq(adj) = 97.40% are demonstrated in Table 4.

Table 4. ANOVA results for lift and drag coefficients

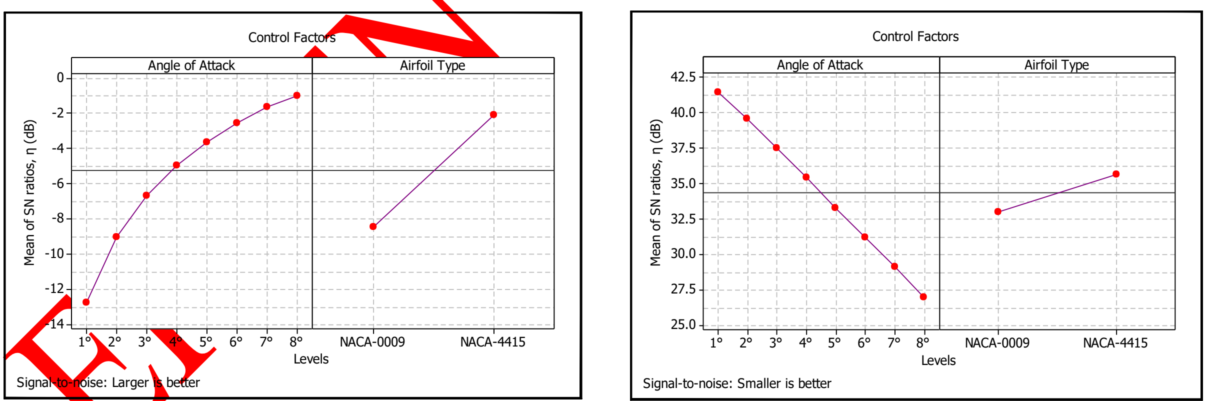
Source	C_L DF	C_L Seq SS	C_L Adj SS	C_L Adj MS	C_L F	C_L P	C_L % Effect	C_D DF	C_D Seq SS	C_D Adj SS	C_D Adj MS	C_D F	C_D P	C_D % Effect
A	7	0.65553	0.65553	0.09365	1380.99	0	53.85	7	0.0021655	0.0021655	0.0003094	79.21	0.000	96.09
B	1	0.56133	0.56133	0.56133	8277.85	0	46.11	1	0.0000607	0.0000607	0.0000607	15.54	0.006	2.69
Error	7	0.00047	0.00047	0.00007			0.04	7	0.0000273	0.0000273	0.0000039			1.21
Total	15	1.21734					100	15	0.0022535					100
R-Sq = 99.96% and R-Sq(adj) = 99.92%								R-Sq = 98.79% and R-Sq(adj) = 97.40%						

As Table 4, the impact ratio of the angle of attack for the lift coefficient was 53.85%, while the airfoil type was calculated as 46.11%. On the drag coefficient, the most effective control factors were determined as the angle of attack with 96.09% and the airfoil type with 2.69%, respectively. The error rate on the lift coefficient was 0.04% and on the drag coefficient it was 1.21%. Depending on the P value, it was calculated that each angle of attack and airfoil geometry had a significant influence on the C_L and C_D. To understand the impacts of angles of attack and airfoil types on the C_L and C_D, the average data of C_L and C_D for all factors based on all levels for CFD and S/N ratio data were solved. Obtained results are demonstrated in Table 5.

Table 5. Response table for C_L and C_D

Level	C_L				C_D			
	S/N data (dB)		Means (-)		S/N data (dB)		Means (-)	
	A	B	A	B	A	B	A	B
1	-12.7394	-8.4613	0.3034	0.4401	41.51	33.03	0.00939	0.02437
2	-9.0041	-2.0610	0.4030	0.8147	39.63	35.69	0.01100	0.02047
3	-6.6593		0.5005		37.57		0.01350	
4	-4.9486		0.5946		35.45		0.01697	
5	-3.6108		0.6844		33.34		0.02156	
6	-2.5255		0.7694		31.24		0.02743	
7	-1.6357		0.8486		29.14		0.03491	
8	-0.9659		0.9153		27.02		0.04459	
Delta	11.7735	6.4004	0.6120	0.3746	14.49	2.66	0.03520	0.00390
Rank	1	2	1	2	1	2	1	2

From Table 5, the optimal lift coefficient was obtained using the NACA-4415 airfoil type with the eighth level of the angle of attack. In addition, the optimum drag coefficient was obtained with the first level of the angle of attack and the NACA-4415 airfoil type. Graphs were drawn using the data in Table 5 for the statistical determination of the impacts of each angle of attack for the C_L and C_D depending on the airfoil type. Graphs containing the impacts of control factors for C_L and C_D were demonstrated in Figures 1a and 1b, respectively.



a) C_L b) C_D

Figure 3. Effects of attack of angles and airfoils on responses

According to Figure 3a, the increase of the angle of attack leads to the increase of the lift coefficient. In Figure 3b, the increase based on the angle of attack provides the increase for the drag coefficient. In addition, the drag coefficient of the NACA4415 airfoil type is lower than that of NACA0009. In a research, the increase of lift and drag coefficients was achieved based on the increase of the angle of attack from 0 degrees to 10 degrees [23]. This study [23] confirms the data obtained for NACA0009 airfoil in present study. In a study, NACA4415 lift and drag coefficients were calculated at various angles of attack and they found that the increase for the angle of attack from 0 degrees to 8 degrees increased the lift and drag coefficients [24]. These results were also found in another study [25]. Both studies [24, 25] support the data obtained in the presented study. In addition, NACA4415 airfoil type can achieve higher lift coefficient than NACA0009. Therefore, in order to obtain the extreme lift coefficient, it can be achieved by using the NACA4415 airfoil type and angle of attack for eight degrees. The minimum drag coefficient can be obtained utilizing the NACA4415 airfoil type and angle of attack in one degree. To obtain the estimated optimum C_L and C_D, optimum levels of significant control factors were used depending on the ANOVA results. These control factors were found to be angle of attack and airfoil type, respectively. The minimum drag coefficient was obtained by using angle of attack for a degree and NACA-4415 airfoil type. The estimated means of lift and drag coefficients can be solved using Equation 17 [32].

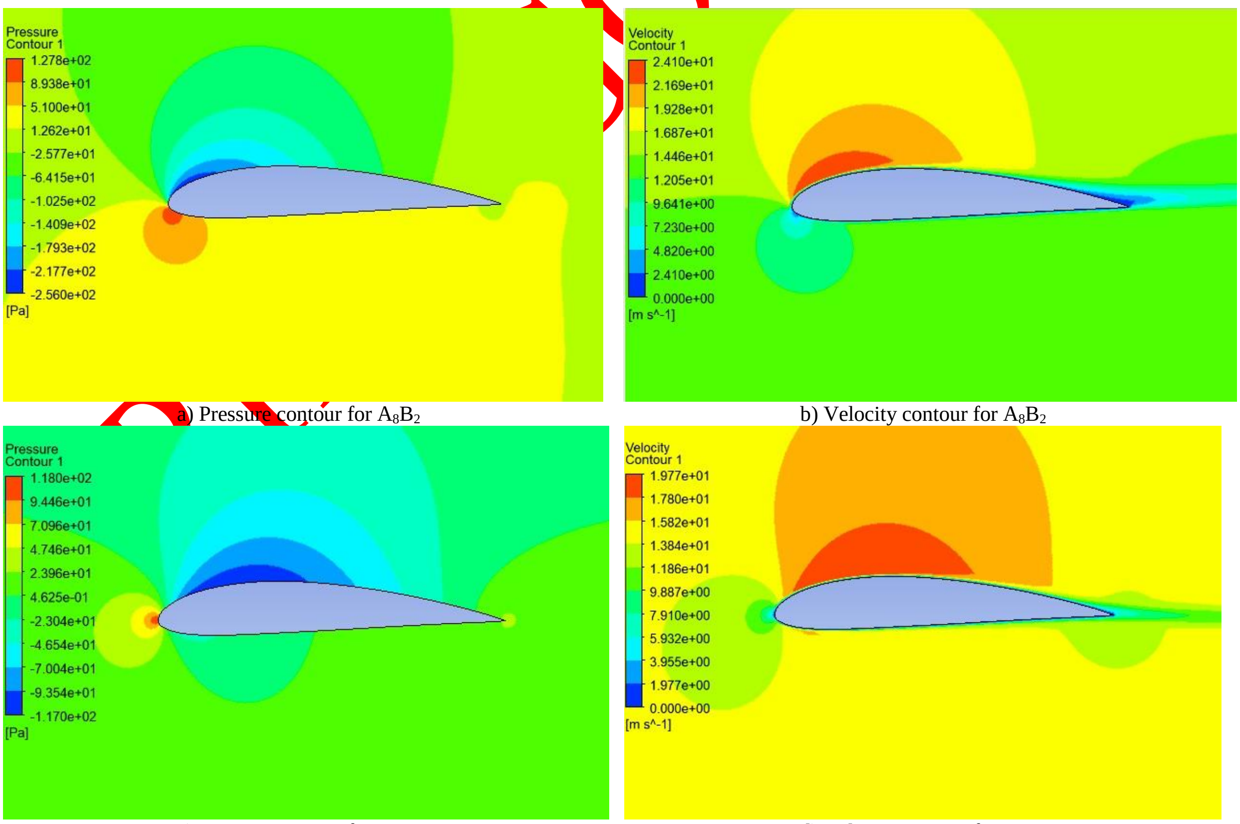
$$\mu_i = \overline{A_\iota} + \overline{B_\iota} - \overline{T_\iota} \qquad (17)$$

where, $\overline{T_\iota}$ expresses the overall mean of response regarding Taguchi L16 orthogonal array. $\overline{T_{CL}}$ = 0.62741 is the average mean of lift coefficient and $\overline{T_{CD}}$ = 0.02242 is the average mean of drag coefficient. $\overline{A_\iota}$ and $\overline{B_\iota}$ show the overall values of responses at the optimum levels. For lift coefficient, $\overline{A_8}$ = 0.9153 is the overall data of lift coefficient based on the eighth level of angle of attack and $\overline{B_2}$ = NACA-4415 is control factor with optimum level for lift coefficient. For drag coefficient, $\overline{A_8}$ = 0.00939 is the average value of drag coefficient regarding the first level of angle of attack and $\overline{B_2}$ = NACA-4415 is control factor with optimum level for drag coefficient. Substituting the values of various terms in Equation 17, μ_{CL} = 1.10259 for estimated lift coefficient and μ_{CD} = 0.00744 for estimated drag coefficient were solved. Comparison of CFD and estimated results were demonstrated in Table 6.

Table 6. CFD and estimated results

Responses	Optimal Designations	CFD Results	Predicted Results	Residuals
C_L	A_8B_2	1.10840	1.10259	± 0.00581
C_D	A_1B_2	0.00521	0.00744	± 0.00223

As Table 6, the difference between the CFD and the estimated Taguchi results depending on the optimum level of angle of attack and airfoil type was quite small. The residuals obtained for the C_L and C_D are calculated as ± 0.00581 and ± 0.00223, respectively. In addition, the pressure and velocity contours depending on the optimum control factors for lift coefficient are presented in Figure 4.



a) Pressure contour for A_8B_2 b) Velocity contour for A_8B_2

c) Pressure contour for A_1B_2 d) Velocity contour for A_1B_2

Figure 4. Pressure and velocity contours

As seen in Figures 4, the change in angle of attack causes pressure and velocity changes in various regions on the airfoil. While the pressure is formed at the minimum value in the regions in which the speed value is maximum, the speed reaches the minimum levels in the areas where the pressure increases.

5. CONCLUSIONS

In the study, effects and optimum levels of angle of attack and airfoil type on performance such as lift coefficient, drag coefficient were evaluated using computational fluid dynamics code ANSYS FLUENT and Taguchi method with L16 orthogonal array including two control factors such as angle of attack and airfoil types such as NACA0009 and NACA4415. Level of importance and contribution ratios of each control factor on responses were solved in accordance with analyses of Signal-to-Noise and Variance. Results analyzed using numerical and statistical methods were described as follows:

- While the lift coefficient of the NACA4415 airfoil was higher than the NACA009 airfoil, the drag coefficient was obtained as lower.
- The increase in the angle of attack for NACA0009 and NACA4415 airfoils causes an increase in the lift and drag coefficients.
- The highest lift coefficient was obtained using NACA4415 airfoil and angle of attack at 8 degrees.
- The lowest drag coefficient was determined using NACA 4415 airfoil with angle of attack of 1 degree.
- The impact ratio of the angle of attack on the lift coefficient was 53.85%, while the airfoil type was determined as 46.11%.
- The most effective control factors on drag coefficient were detected as the angle of attack with 96.09% and the airfoil type with 2.69%, respectively.
- The differences between the estimated and numerical analysis results in accordance with the optimum lift and drag coefficients are calculated as ± 0.00581 and ± 0.00223, respectively.
- Low velocity distributions were detected in the regions of high pressure on the airfoils.

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DECLARATION OF ETHICAL STANDARDS

The authors of this article declare that the materials and methods used in their studies do not require ethical committee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS

Savaş EVRAN: Wrote the manuscript and analysis the results.

Salih Zeki YILDIR: Performed the numerical calculations.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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